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Design and Operation of Modern Lime Works.—VI.*

By N. V. S. KNIBBS, D.Sc.

Mixed Feed Kilns : The Theory of Mixed-feed Lime-burning.

THE theory of the mixed-feed kiln, in which a non-volatile fuel is mixed with stone either uniformly or in layers at the charging point of the kiln, is often assumed to be simple because heat is generated by combustion in the immediate vicinity of where it is used ; but it is obvious from the great difference in results obtained by different lime-burners and the experience required for successful operation of these simple kilns that the assumption is incorrect. When it is realised that a mixed-feed kiln without the stone would correspond to a very high gas producer—not to an ordinary furnace fire—the difficulties will be appreciated. The exhaust gases from a mixed-feed kiln ordinarily contain some carbon monoxide, and the presence of a large amount is generally known to involve a waste of fuel, but the literature of lime-burning does not help one to prevent it. Usually it is said that enough air must be admitted to provide oxygen for its

* Previous articles in this series were given in our issues for January, February, March, April and May, 1937.

combustion to carbon dioxide, but the usual effect of admitting more air is to raise the height of the high-temperature zone in the kiln, which must be checked by drawing and charging more rapidly. In an ordinary mixed-feed kiln there is always an excess of carbon in the upper parts so that there is always enough carbon present to change all the carbon dioxide to carbon monoxide in accordance with the reaction $\text{CO}_2 + \text{C} = 2\text{CO}$.

When air is passed through an excess of coke or other carbonaceous fuel the composition of the exit gases may depend on several factors. If contact is

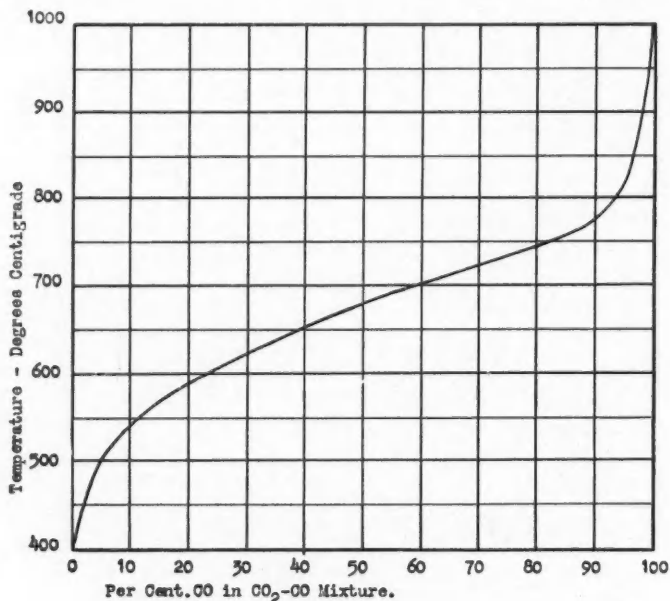


Fig. 18.—Composition of the Carbon Monoxide—Carbon Dioxide Mixture in Equilibrium with Carbon.

sufficiently prolonged for equilibrium to be reached the composition at atmospheric pressure is dependent solely on the temperature and it is shown in Fig. 18, based on the results of Boudouard and of Rhead and Wheeler. At lime-burning temperatures of 900 deg. C. and upwards the equilibrium mixture is nearly all carbon monoxide. At points higher up the kiln, where the temperature is lower, the equilibrium mixture is higher in carbon dioxide, and at 400 deg. C. it is nearly pure carbon dioxide, but it has been shown that the rate of the reaction $2\text{CO} = \text{CO}_2 + \text{C}$ is extremely slow and in ordinary technical processes it is negligible. It has no bearing on the composition of the gases in a lime kiln. We know that in a mixed-feed kiln the proportion of carbon monoxide in the

exhaust gases is ordinarily low. Why is it that the equilibrium proportion is not approached?

Fuel Reactivity.

The explanation lies in the relatively low reactivity of lime-burning fuels. The difficulty of igniting and keeping alight a fire of hard coke or anthracite as compared, for example, with low temperature coke or soft coal, is well known, but although that difficulty is due to the low reactivity of the former fuels little investigation of the property has been carried out except on metallurgical cokes. A free-burning fuel is not only highly reactive in its combination with oxygen to form carbon dioxide in a shallow fire or in the lower parts of a thick fuel bed, but it is also reactive in the upper parts of a thick bed where the endothermic reaction to carbon monoxide takes place. If a fuel could be found which was highly reactive to oxygen, so that burning to carbon monoxide is rapid and complete, yet inactive to carbon dioxide so that the dioxide to monoxide reaction is slow, it would be the ideal mixed-feed fuel, but such a fuel is unknown and probably an impossibility.*

Investigation of fuel reactivities has been confined mainly to different kinds of metallurgical coke because of the importance of the property in blast-furnace practice, where a low reactivity to carbon dioxide is desired. Several investigators have compared the rate at which different cokes burn in air or oxygen under standard conditions, while others measured the rate of reaction with carbon dioxide at a high temperature. The most extensive tests were carried out at the Fuel Research Laboratory (Fuel Research, Tech. Papers Nos. 18, 22 and 25) measuring the rate of reaction of carbon dioxide on the fuel at 950 deg. C. Wood charcoal is highly reactive and gas retort coke moderately reactive, while various metallurgical cokes have low reactivities, beehive coke having least. Cokes made of strongly-caking coals have low values, and high coking temperature gives low reactivity. Blending of non-caking with caking coal and impurities, especially reducible iron, increases reactivity. Unfortunately the investigations have not been extended to anthracites, bituminous coals, and other lime-burning fuels, and further consideration will be deferred until these fuels are discussed.

Reactivity and Shaft Capacity.

The size of shaft required for lime burning has already been discussed,† but it was there assumed that the rate of heat generation in the burning zone by combustion of the fuel was high in comparison with the rate of transference of heat to the lime. In a mixed-feed kiln using a fuel of low reactivity combustion may be so slow as to constitute the limiting factor and to fix the size of burning zone necessary, and there are no reliable data available to assess, even roughly, the size required. The least reactive fuels are used mainly in continuous kilns operated at high capacity with a draught that ensures rapid combustion when the limitation is seldom of importance, and in kilns worked slowly with natural

* Nevertheless, Arend and Wagner (*Rev. Met.* 21, 585, 1924) suggest that modern coking methods may be able to produce something of the kind.

† "Cement and Lime Manufacture," April, 1937, p. 123 *et seq.*

draught a more reactive fuel must necessarily be used. Nevertheless, it would seem likely that the low shaft capacity of the older types of mixed-feed kiln is largely due to the rate of combustion of the fuel, which lengthens the burning zone but which also serves to limit the temperature and therefore to reduce overburning.

Thermal Efficiency.

In an ordinary mixed-feed kiln the conditions influencing efficiency are somewhat complicated. A high burning-zone temperature increases the efficiency of calcination* but at the same time a rise of temperature increases the rate of carbon monoxide formation and therefore the loss of fuel as carbon monoxide in the exhaust, and it is evident that the kiln temperature permissible without undue heat loss will depend on the reactivity of the fuel. It so happens that the two fuels, coke and anthracite, which are low in volatiles, and therefore preferred as mixed-feed kiln fuels, are also of low reactivity. They are therefore capable of being used without undue monoxide formation at higher kiln temperatures than other fuels such as soft coal. If so excellent a non-volatile fuel as wood charcoal were available at the same price as coke it would be uneconomic for mixed-feed lime-burning, in spite of its low ash content, because it is so reactive that at lime-burning temperature equilibrium is rapidly attained and the exhaust gases are high in carbon monoxide.

The temperature of the burning fuel in a kiln depends on the rate at which it is burning and the rate at which it is giving up heat. In a deep fire-bed or in the bed of a gas-producer the fuel is surrounded by fuel so that loss by radiation is almost eliminated and all the heat is carried away by the gases. The temperature therefore rises very high and the reaction to carbon monoxide becomes so rapid, even with coke, that equilibrium is closely approached and the issuing gases contain very little carbon dioxide. In a lime kiln in which the fuel is distributed uniformly amongst the limestone each piece of burning fuel is surrounded by lime in process of calcination, and therefore the fuel loses heat by radiation and otherwise directly to the lime. The temperature is therefore maintained much lower than in a producer bed. The higher the velocity of the air supplied to the fuel the more the heat generated, and although the rate of loss of heat to the lime is also increased by increase of velocity the rate of such increase is very much less than that of heat generated. Consequently the temperature increases with increase of draught.

A fuel of sufficiently high reactivity would prevent overburning in a mixed-feed kiln because the endothermic reaction to monoxide limits the temperature in the burning zone, and if use could be made of the combustible gas formed, either outside the kiln or at a higher zone of the kiln (as suggested later), this method of operation would have economic possibilities.

A fuel of low reactivity favours low carbon monoxide in the exhaust and permits a higher burning temperature without undue loss from that cause, but it also increases the difficulty of ensuring complete combustion of the carbon in

* See "Cement and Lime Manufacture," January, 1937, p. 5 *et seq.*

the fuel. The less reactive the fuel the higher is the ignition temperature and therefore the greater the tendency for partially burnt fuel to be drawn with the lime. From one aspect a high ignition temperature is an advantage because it avoids the production of carbon dioxide in the cooling zone where it would recarbonate the lime, but excessive loss by unburnt carbon in the fuel may be as serious as high carbon monoxide in the exhaust. Lime-burners using coke are familiar with the difficulty of ensuring complete combustion in a kiln. When it is being operated on low output it is difficult to keep coke alight in the kilns, and for this and other reasons the fuel may be charged in layers instead of uniformly mixed with the stone.

Admixed and Layered Charging of Fuel.

In mixed-feed kilns operating under natural draught the usual practice is to charge the fuel in layers, which may be from about 3 in. to 10 in. thick, between layers of stone. Depending on the thickness of the layer and the evenness of following down of the kiln the fuel then burns under conditions resembling those of a furnace fire, and an ash low in combustible content is more easily attained. There are also reasons for charging in layers other than the better combustion and easier maintenance of the fire. When kilns are charged manually it is easier to ensure even distribution of fuel over the whole area by charging it separately in a layer, and there is less contact between lime and fuel, so that it is easier to pick out clean lime than when the fuel is evenly mixed. However, unless the layers are thick there is considerable admixture during the descent through the shaft, and thick layers are undesirable because they cause uneven and inefficient calcination.

It is evident that a kiln in which the fuel is uniformly distributed through the stone must be thermally more efficient than one in which it is layered, and the more rapid transmission of heat from fuel to lime by radiation must permit more rapid combustion without carbon monoxide formation. In high-capacity kilns operated under forced or induced draught a uniform mix is preferable and is usually employed, but in natural-draught kilns charging in layers is preferred mainly because of easier maintenance of the fire. The more reactive or free-burning the fuel the more desirable it is to have uniform distribution rather than layers, and therefore when coal is the fuel a uniform mix is generally to be preferred. It will be realised that, depending as it does upon the fuel, the draught, the scheme of charging and drawing, and also sometimes on the nature of the limestone, the best method of charging is not easily assessed by rule, and it is largely on this account that the successful operation of the older types of mixed-feed kiln depends so much on the experience of the lime-burner. In modern high-capacity types, operated continuously by mechanical draught, skill of operation is replaced by skill of design, ensuring uniform fuel distribution by mechanical means and in maintaining suitable draught conditions.

Carbon Monoxide and Volatile Combustibles in the Exhaust.

What is the thermal loss involved in a given percentage of carbon monoxide in the exhaust from a mixed-feed kiln? When carbon burns to carbon dioxide

it generates 8,110 C.H.U. per pound of carbon, and when carbon monoxide is formed the heat evolved is only 2,420 C.H.U. per pound of carbon, that is to say, 0.30 of the full heat of combustion. An efficient mixed-feed kiln burning a non-volatile fuel will have an exhaust containing between 30 and 40 per cent. carbon dioxide, of which an average of about 17 per cent. comes from combustion of the fuel. Any carbon monoxide in the exhaust reduces this 17 per cent., and each 1 per cent. represents a loss of $70 \div 17$, or about 4 per cent. of the heating value of the fuel. The loss is therefore serious, even with relatively low percentages of monoxide, in addition to which is the disadvantage of a poisonous exhaust.

Very little information has been published about the carbon monoxide content of lime kilns under varying conditions. Block* gives CO figures up to 10.8 per cent. in an experiment with a carbon dioxide pump working too slowly and with insufficient drawing, and he quotes similar high figures obtained by others, but they do not appear to be normal figures. They may have been obtained soon after reducing the draught, and when the kiln was at a temperature due to the previous operation at higher draught. He also quotes monoxide percentages varying between 1.9 and 4.3 in a kiln operating normally, but fuel and other conditions are not given.

When a fuel containing volatile combustible matter is used in the simple type of mixed-feed kiln there is thermal loss not only due to carbon monoxide formation but also because of the loss as smoke of nearly all the volatile matter, which also creates a smoke nuisance. Bituminous coal is therefore used in these kilns only when it is very much cheaper than coke or anthracite and where the emission of heavy smoke is tolerated.

Mixed-feed Kilns with Secondary Air.

The obvious way to avoid carbon monoxide in the exhaust would be to admit secondary air to the kiln if it is practicable to do so. Shaft kilns have been proposed in which air is introduced through ports in the side at the burning zone, and sometimes it is proposed to preheat that air by drawing it through ducts in the hot lining, but unless the kiln is a narrow one such air will not mix uniformly with the kiln gases. The best design of the kind is that embodied in the Spencer kiln.

The original Spencer kiln (P. W. Spencer, English patent No. 767 of 1870) was domed (A) or arched (B) as shown in *Fig. 19*, with ducts for adding fuel to the hollow spaces formed under the dome or arch. The fuel was thus introduced not at the top but one-third to half-way down the shaft, and secondary air could also be admitted at the same height. Below the dome or arch the kiln operated as an ordinary mixed-feed kiln, but the carbon monoxide and the volatile gases arriving or driven off at this point had the remainder of the kiln in which to burn, and air could be supplied for their combustion. A later form (W. Spencer, English patent No. 16,043 of 1894) narrowed the shaft and provided fuel inlets at two different heights, and still later (W. Spencer, English patent No. 3094 of

* Block. *Das Kalkbrennen*, 2nd ed., p. 285 *et seq.*

1900) the form shown in *Fig. 20* was adopted. Here there is an upper arch thrown across the kiln at *a*, with fuel ducts leading to the centre of the kiln, and at *b*, about half-way down, the shaft is constricted to a narrow neck under which it opens out quickly so that the natural angle of the stone and lime leaves a space over which fuel is distributed through openings *c*. Air ducts are provided leading into the kiln at *b* and designed to preheat the air by drawing it through the lining of the lower section. The principle of the original Spencer kiln has been employed in several kilns known by other names, such as the Copenhagen or Aalborg kiln, the Brockham kiln, and the Ryan kiln (English patent No. 20,874 of 1902).

The volatile combustibles and the carbon monoxide are not easily burnt in the upper sections of a kiln. They are highly diluted with nitrogen and carbon dioxide and are therefore difficult to burn completely, and there is the further difficulty of securing proper admixture with air before the gases arrive at a point below their ignition temperature. The ignition point of carbon monoxide is

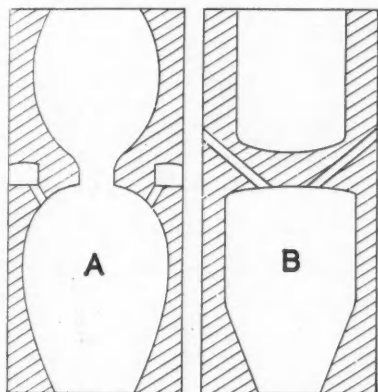


Fig. 19.

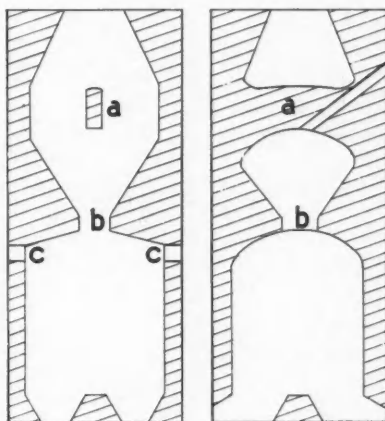


Fig. 20.

about 650 deg. C. and that of the dilute mixture must be even higher. For these reasons none of the kilns gives a smokeless exhaust when using bituminous fuel, but the Spencer kiln shown diagrammatically in *Fig. 20* has moderately efficient secondary combustion because of its special design. An important feature is the narrow neck at *b*. Its effect is to concentrate the flow of hot gases through a narrow channel, and the resulting high velocity of flow greatly facilitates mixing with the air admitted there and also promotes combustion. The kilns are ordinarily drawn by day only, and the facilities for adding fuel at two levels are an aid to efficient operation under these conditions. The Spencer kiln is still the most efficient kiln of its kind adapted to the use of bituminous coal.

Few attempts have been made to modernise a kiln of this type. The heavy lining construction, doming, and arching would easily be destroyed by excessive

heat, and the kiln is therefore not well adapted to forcing with mechanical draught. Modern mixed-feed kilns nearly all operate on a fuel practically free from volatiles, and when bituminous coal must be employed no attempt is made to utilise its content of volatile combustibles. It is wasteful to use bituminous fuel in ordinary mixed-feed kilns, and the smoke nuisance prevents this being done in most districts, but the producer-gas-fired kiln is the modern unit best adapted to such fuel.

Purity of Lime from Mixed-feed Kilns.

Lime from a mixed-feed kiln is subject to contamination from the fuel ash, from sulphur in the fuel, and by recarbonation. The degree of contamination by ash depends upon the mode of operating the kiln, the maximum temperature, and the nature of the ash. If fuel and stone are charged in thick layers, and if they pass through the kiln as far as the cooling zone without mixing, much of the lime will not come in contact with the ash until it is too cool to matter, provided that the ash is not so light and fine that it is carried forward by the draught. Such thick layers, however, can be employed only at the sacrifice of thermal efficiency and also at the risk of overburning part of the lime. Temperature is an important factor. It has been shown that silica and the other impurities will combine with lime at the lowest temperatures at which calcination takes place, but combination is extremely slow at temperatures up to 1,000 deg. C. or more, and consequently a pure lime may easily be separated from the mixture drawn from a mixed-feed kiln operated at low temperature. When burning the usual size of kiln stone such low temperatures are maintained only at the sacrifice of efficiency, and even when the average temperature is low there is always local heating adjacent to the burning fuel and therefore just in the position to induce combination of the ash with the outside of the lumps of lime. The presence of iron in coal ash reduces the temperature required for the formation of compounds with lime, and the compounds produced are more objectionable than those of silica and alumina alone. Fuels low in iron are therefore desirable for lime-burning, and they may be used at higher temperatures. It is sometimes said that when burning limestone that is not of the highest purity the contamination introduced by ash in a mixed-feed kiln is of little importance, but this requires qualification. The small lime produced in burning must necessarily be contaminated with ash, and therefore be of much less value than uncontaminated small lime, and the large lime, although it may be separated from the bulk of the ash, and therefore obtainable with an average composition only slightly inferior in respect of ash content to that of lime made out of contact with the fuel, has the small amount of ash concentrated on its surface, and therefore is much more liable to cause trouble in use than a larger amount of impurity distributed through the original stone.

Most of the sulphur in the fuel used in a mixed-feed kiln is transferred to the lime, forming calcium sulphate and generally some sulphide,* and the lesser proportion so transferred in a producer-gas-fired kiln is generally recognised as

* "Cement and Lime Manufacture," July, 1937, p. 197.

one of the advantages of the latter. It is not obvious why there should ordinarily be less contamination in a gas-fired kiln, using fuel of the same sulphur content. During combustion or gasification the sulphur in a fuel is partly evolved as gas and partly (generally to a much lesser extent) left in the ash. Possibly the proportion remaining in the ash is greater when the fuel is gasified than when it is completely burnt, but there also seems to be somewhat less absorption by the lime so that the exhaust from a gas-fired kiln contains more sulphur dioxide than that of a mixed-feed kiln. However, there are few analytical data available, and these are inconclusive because of the different character of the fuels used in the two types of kiln. Possibly the advantage often claimed for the producer-gas-fired kiln is exaggerated, but whereas in the mixed-feed kiln it is impossible to reduce the sulphur contamination from any given fuel, in a producer it is possible to absorb some of it so that the gas contains less, and it is also possible, when necessary, to cool and wash the gas free from sulphur.

The recarbonation of lime in mixed-feed kilns of the older types is of much more frequent occurrence than is generally recognised, and lime which is called overburnt is often, in reality, recarbonated.* A piece of fuel that is slow in burning may descend into the cooling zone of the kiln and, in fact, some incompletely burnt fuel is almost invariably drawn with the lime. Such fuel will continue to burn and generate carbon dioxide as it passes down the cooling zone, to a point depending on its reactivity. The carbon dioxide content of the gases, even immediately in contact with the fuel, cannot exceed 21 per cent. and ordinarily it will be very much less. Recarbonation can therefore occur at a maximum temperature of about 790 deg. C. (corresponding to 21 per cent.) and ordinarily less, say, 720 deg. C. (corresponding to about 5 per cent.). At such temperatures fuel of low reactivity burns very slowly, but a reactive fuel is capable of causing considerable recarbonation. The delayed combustion of fuel, however, is not the only cause of recarbonation. In short kilns with open tops the wind is easily capable of causing momentary down-draughts which carry carbon dioxide down into the cooling zone, causing recarbonation, and when kilns are damped down during week-ends or for other reasons diffusion downwards of the gas may occur with similar results. In modern continuous kilns with mechanical draught and using coke fuel recarbonation should be small.

Kilns for Natural Draught.

The great majority of mixed-feed kilns in Great Britain supplying lime to the ordinary market operate under natural draught, and they vary widely in dimensions and general design. Modern kilns of this type, of which there are relatively few, combine a simplicity in the design of the shaft with robustness of construction and embody improved methods of charging and discharging. *Fig. 21* shows such a kiln. It is an open-top kiln 60 ft. high and 12 to 15 ft. internal diameter, having a capacity of 40 tons of lime a day, all of which is charged and discharged in an 8-hour day shift. The inclined hoist fills an electrically-operated charging hopper which can be traversed to the centre of the

* "Cement and Lime Manufacture," July 1937, p. 195.

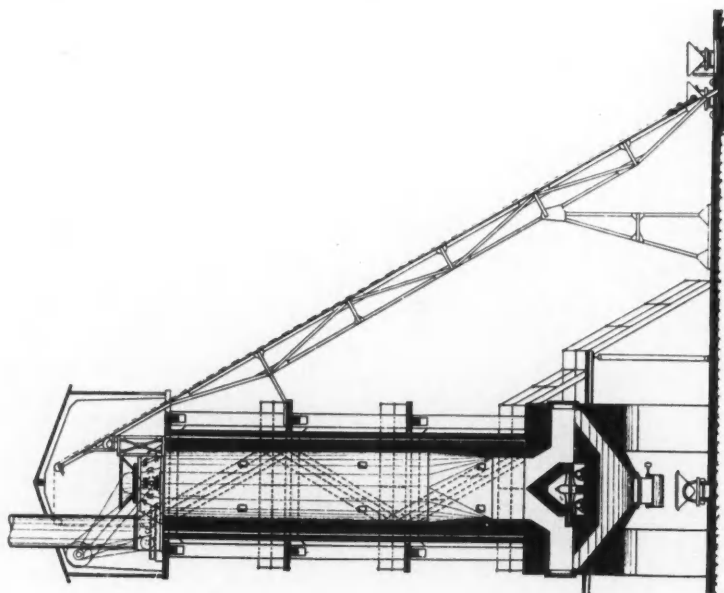


Fig. 22.

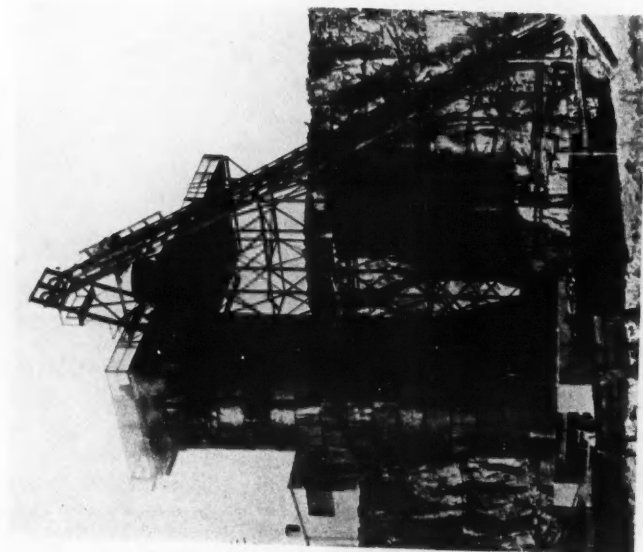


Fig. 21.

kiln and also to other kilns (not shown in the photograph) and tipped, control being from the house seen behind the kiln. Discharge from each kiln is by means of four roller feeders delivering to a belt conveyor where the lime is sorted. It will be observed that there are no inspection doors in the shaft.

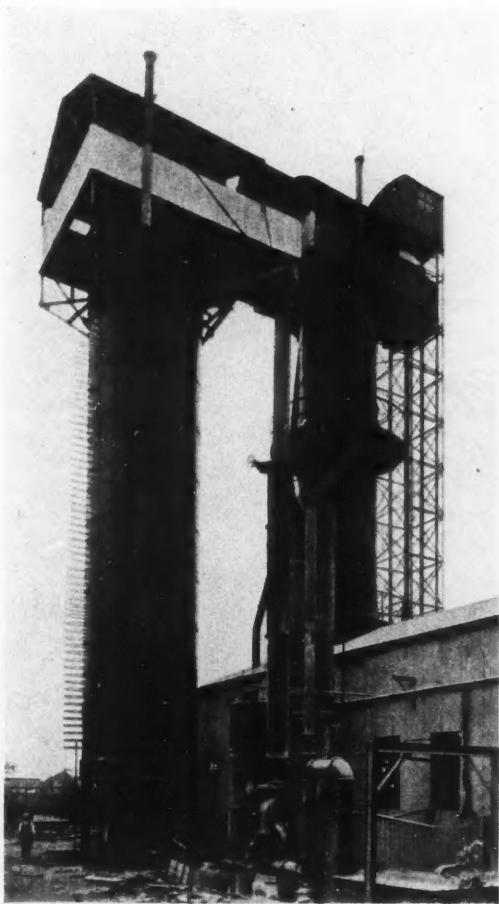


Fig. 23.

A kiln of German design (Curt von Grueber, Berlin) is shown diagrammatically in *Fig. 22*. Here the inclined hoist discharges into a hopper which rotates about a vertical axis and is designed to spread the charge evenly over the whole shaft

area. Discharge is automatic by a type of discharging gear already described.* The capacity is said to be from 20 to 70 tons a day with a shaft diameter of 5 to 10 ft. and a height of 35 to 50 ft., but the capacities would be attained only with mechanical draught.

Kilns with Induced Draught.

Mixed-feed kilns with induced draught are usual at plants where both lime and carbon dioxide are used in a chemical process, e.g. ammonia-soda plants and sugar factories. The gases are required under pressure, and the blower

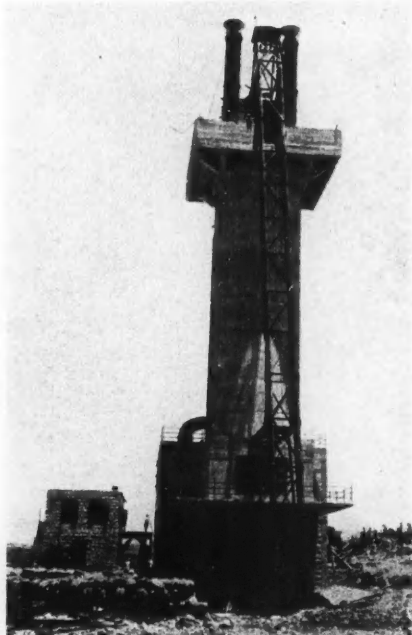


Fig. 24.

or compressor serves also to induce the draught through the kiln. The gases are also required pure, and to simplify the process of purification a smoke-free exhaust is desirable; consequently good coke is nearly always the fuel employed. These kilns produce lime for a special purpose, and often the quality is of less moment than the carbon dioxide content of the exhaust. They are therefore of less importance to the lime industry than other kilns, but it is of interest to note that chemical-plant kilns have generally been of simple design, free from the elaboration which has in the past characterised many attempts at improving

* Type F, "Cement and Lime Manufacture," March, 1937, pp. 81 and 82.

other kilns. They are necessarily closed-top kilns and the stone is charged through an automatic or mechanically-operated bell. The left-hand kiln in *Fig. 23* (Messrs. Power-Gas Corporation Ltd.) is of this type, the gases being drawn off directly through a centrifugal fan-cleaner.

Kilns with Forced Draught.

Mixed-feed kilns in which the air is blown in under pressure have been developed and are largely used in Germany and elsewhere on the Continent. The advantages and difficulties of forced draught have already been discussed*, and it is to be noted that the advantages are magnified when small and mixed stone, which offers high resistance to the draught, is to be burnt. Forced draught is well adapted to use with mechanical dischargers, which can be arranged to empty into totally-enclosed hoppers of ample dimensions which are opened only for a few moments for emptying. For example, the kiln shown in *Fig. 22*, with a larger hopper beneath, is suitable. *Fig. 24* is a photograph of a recent forced-draught kiln (Fried. Krupp Grusonwerk, A.G.), constructed of concrete. The air inlet pipe is seen entering at a considerable height, allowing ample space for the discharging mechanism (a reciprocating table) and large receiving hoppers below; in fact, the height of the discharging arrangements in this type of kiln is sometimes nearly as great as that of the shaft itself. The air is often carried to a central inlet with cowl placed several feet above the discharging mechanism. When forced-draught kilns are discharged by hand, the blower is generally stopped to avoid excessive blow-out of air and dust. Forced-draught kilns may be open or closed at the top, but if open they should have a stack submerged enough to draw off all the exhaust gases, unless arrangements are made (as in the kiln shown in *Fig. 21*) to charge from a distance.

Other Types of Mixed-feed Kiln.

As already mentioned, there are several kinds of kiln in use in which the fuel is wholly or partly fed in at one of two positions well below the exhaust-gas outlet. The Spencer kiln and various named and unnamed modifications of it are used on limestone, and the Brockham kiln, which is essentially of the type of A in *Fig. 19*, is used considerably for burning chalk. Brockham kilns continue to be built, with minor modifications in the design, but no attempt appears to have been made to design a really efficient kiln of the type, based on a study of the material to be burnt. Chalk, and particularly the lower chalk which burns to greystone lime, is difficult to burn cheaply to a good product and there is scope for great improvement in present practice. The difficulty is enhanced by the illogical demand for burnt lime in the form of large lumps. Chalk lime is particularly difficult to produce cheaply in large lumps because it tends to break up in the kiln and because its conductivity is low, and that difficulty is the main reason for its high cost of production as compared with that of limestone lime. The development of a mixed-feed kiln to burn small chalk† is long overdue.

* "Cement and Lime Manufacture," March, 1937, pp. 84 and 85.

† See "Cement and Lime Manufacture," Feb., 1937, p. 61.

Effect of the Addition of Stone Dust to Cement on the Qualities of Concrete.

THE effect on the strength of concrete of the addition of stone dust to cement has been widely discussed, and numerous laboratory tests have been made, and, although all standard specifications forbid such an addition, the simultaneous grinding of inert materials with clinker within reasonable limits still finds partisans. This subject is dealt with by Mons. M. J. Bolomey, of the University of Lausanne, in a recent number of *Travaux*, of which the following is a translation.

A particular virtue is attributed to simultaneous grinding as a means of ensuring an intimate mixture of cement and stone dust. The degrees of fineness of cement and stone dust being different, the particles of one of these bodies can partially fill the voids in the other so that the compactness of the concrete will be improved. Opinions still diverge on an essential point: some theorists claim that the addition of an inert material causes the cement to be more finely ground so that the particles more completely fill the capillary voids of the concrete, while others hold that the stone dust fills the voids between the cement particles.

These are simple hypotheses which have not been verified by laboratory tests. It is probable that in certain cases the stone dust will be more finely ground than the cement, and that in other cases there will be a contrary result according to the relative ease of grinding the clinker and the inert material. The only point which is established is that, by reason of the simultaneous grinding, the mixture of stone dust and cement will be intimate and homogeneous.

It may be that the addition of hard siliceous rock to clinker facilitates the fine grinding of cement, and that therefore the chemical energy of the latter is more rapidly and completely available. It is necessary to observe, however, that actually the majority of factories are able to produce cement as fine as is necessary without the addition of hard inert material. It is not desirable to extend the fineness of grinding beyond certain limits, otherwise too large additions of gypsum are necessary to regulate the setting-time, the contraction is accentuated, and the cement deteriorates on storage.

An opportunity was taken of studying two adulterated cements obtained by simultaneous grinding of clinker and calcareous sandstones. In both cases the initial hardening of the pure cement has been more rapid than that of the adulterated cement, which does not seem to indicate a finer grinding of the latter.

The addition of inert material to cement has been justified by theoretical considerations (a little nebulous and not controlled by experiments) concerning the fineness of grinding of the cement and the density of concrete, and also by exact laboratory tests. It is claimed that by standard specification tests (which are the only ones to which they refer) the strength of mortar with adulterated cement is always proportionately greater than that of pure cement taking into account the effective proportions of cement. Thus, for example, a cement containing 10 per cent. of adulterant is said to have practically the same strength by standard tests as pure cement, while adulteration with 20 per cent. involves

a decrease in strength of less than 10 per cent. How can these results of easily controlled experiments be explained without admitting that a favourable effect follows the addition of stone dust to cement?

The following are the essential results of one of a series of investigations made with pure cement and with various additions of stone dust.

| Cement, per cent. | .. | .. | .. | .. | .. | 100 0 | 96 4 | 92 8 | 88 12 |
|--|----|----|----|----|----|--|---------|---------|----------|
| Stone dust, per cent. | .. | .. | .. | .. | .. | Compression strength— 28 days—kg/cm. ² | | | |
| Standard mortar 1 : 3—rammed | .. | .. | .. | .. | .. | 511 | 509 | 500 | 494 |
| " " —plastic | .. | .. | .. | .. | .. | 325 | 325 | 321 | 305 |
| Concrete with 150 kilos. of cement per cubic metre | .. | .. | .. | .. | .. | 70 | 68 | 61 | 55 |
| " " 225 | .. | .. | .. | .. | .. | 170 | 167 | 151 | 140 |
| " " 300 | .. | .. | .. | .. | .. | 308 | 298 | 280 | 267 |

This table shows with, for example, 12 per cent. of stone dust, the decrease in strength is 3 per cent. for standard mortar (rammed) ; 6 per cent. for standard mortar (plastic) ; 22 per cent. for concrete with 150 kg. of cement per cubic metre ; 18 per cent. for concrete with 225 kg. of cement per cubic metre ; 13 per cent. for concrete with 300 kg. of cement per cubic metre.

Thus, while standard laboratory tests show a fall in strength proportionately much less than the adulteration with stone dust, the reverse result is shown for concrete as used in construction. The strength of the latter depends solely upon the effective proportion of cement, the stone dust acting as an inert material. Any adulteration of the cement involves a fall in strength corresponding to the reduction in the percentage of pure cement.

Similar tests have been made with various cements and different stone dusts, the adulteration having been made either by simultaneous grinding or by mixture of the inert material and the cement separately ground, and the results have always been the same, namely, relatively small reductions in strength in standard tests and much greater reductions for concrete similar to that used in construction.

How can these apparently contradictory results be explained? They are due essentially to serious defects in the usual standard tests. Standard mortars (1:3) have a very high cement content (500 to 540 kg. of cement per cubic metre); they are made with standard sand having uniform grain sizes and thus very badly graded and necessitating a large quantity of gauging water or a great deal of ramming if the mortar is to be impermeable and homogeneous. Thus, the standard Swiss specification (1935) contains the following composition for the mortar:

| | By weight (kg.). | Specific gravity. | By volume. |
|--------------------------|------------------|-------------------|-----------------------------|
| Cement (per cubic metre) | 495 | 3.10 | 160 litres per cubic metre. |
| Sand | 1,485 | 2.65 | 560 |
| Water | 218 | 1.00 | 218 |
| Voids | — | — | 62 |
| | 2,198 | — | 1,000 |

The voids in the sand comprise 44 per cent. of the volume of the mortar; they are only filled to the extent of 38 per cent. by the cement and the gauging water. Everything is abnormal in standard mortar. Thus, in spite of a cement content in the proportion of about 500 kg. per cubic metre, its strength exceeds only slightly, because of great porosity, that of field concrete containing 300 kg. of cement per cubic metre with aggregate suitably graded from 0 to 20 mm. and gauged with 160 litres of water.

By reason of the exaggerated proportions of standard mortars, part of the cement serves principally to fill a portion of the voids of the sand and can thus be replaced without ill effect by stone dust. This effect of the even grading of the sand is shown by the considerable reduction in strength of mortars with standard sand (which is not observed in the same measure with well-graded concretes) if the proportion is reduced, for example, from 1 : 3 to 1 : 4.

By replacing 10 to 20 per cent. of cement by stone dust of lower density, the volume occupied in standard mortar by the same weight of binding material will be increased, and thus the compactness of the mortar will be improved and increased ramming will be needed to obtain the constant density of 2.20 laid down by the Swiss specification. The increased strength resulting from the greater compactness and the more intense ramming should compensate and more than compensate for the decrease in strength which is the logical result of the lower proportion of cement which, however, is still very high.

The Swiss standard tests favour cements of low density at the expense of those of higher density which are also better. If, therefore, the strengths obtained by the standard tests of cement adulterated to the extent of 10 per cent. are little inferior to those obtained with pure cement, this is not due to a useful effect of stone dust on cement but to a change of the conditions under which standard tests are made (i.e., greater compactness, harder ramming, etc.).

It is quite otherwise for field concrete. The proportion of cement being limited, each particle of cement is needed to obtain the required strength, and cannot be diverted from this fundamental object to remedy a defect of ultimate compactness. The compactness of concrete should be ensured by suitable grading of the aggregate and not by an increase in the proportion of cement used with this aim alone or by intense ramming, such as can only be used in exceptional cases. This is why the strength of field concrete made with adulterated cement is always lower than that of concrete with the same proportion of pure cement, and is proportional to the reduction in the effective quantity of cement used.

It follows from this argument that the addition of stone dust should be condemned in every case. It constitutes an illusory economy: it deceives the buyer as to the real quality of the cement since the control tests are nearly always made to standard specifications and few laboratories are equipped to make concrete tests.

The danger of adulteration is shown by the following example. A maker of aluminous cement, with a view to reducing the high price, adulterated it to the extent of 50 per cent. by simultaneously grinding the clinker with an equal

weight of inert material. Compression tests of mortar made by the old standard method of mechanical ramming gave the following results :

| | Pure cement. | Adulterated cement. |
|----------------------------------|--------------|---------------------|
| 3 days (kg. per sq. cm.) | 706 | 361 |
| 7 " " " " " " | 817 | 422 |
| 28 " " " " " " | 868 | 483 |

As the specification then in use for Portland cement prescribed a strength of 325 kg. per sq. cm. at 28 days, the manufacturer concluded that the adulterated aluminous cement corresponded in quality to a good Portland cement, and advertised it accordingly. This cement was used for the construction of a retaining wall in which the stress did not exceed 2 to 3 kg. per sq. cm. and for which the contractor thought the concrete could be mixed with 200 kg. of the adulterated cement per cubic metre. The strength of the resulting concrete did not exceed 40 to 60 kg. per sq. cm. at 28 days, and during the first winter the concrete was considerably damaged by frost and costly repairs were necessary. This could have been prevented if it had been realised that a proportion of 200 kilos of adulterated cement (50/50) corresponds to an effective proportion of only 100 kg. of cement per cubic metre, which is manifestly insufficient even with the best cement. The author was called in to advise, and made comparative compression tests on field concretes with the following results on concrete mixed with 200 kilos of cement and 195 litres of water per cubic metre :

| | Compressive strength (kg. per sq. cm.). | |
|--|---|----------|
| | 7 days. | 28 days. |
| Pure aluminous cement | 151 | 183 |
| Adulterated aluminous cement (50/50) | 45 | 63 |
| Pure Portland cement | 69 | 102 |

While the standard tests at 28 days showed the adulterated cement to have reached 53 per cent. of the strength of the pure cement, this proportion fell to 34 per cent. in tests of concrete made with the adulterated cement and compared with concrete made with pure cement. Although the strength at 28 days by standard tests of adulterated aluminous cement was greater than that of pure Portland cement, the strength at the same age of concrete mixed with cement in the proportion of 200 kg. per cubic metre of Portland cement exceeded by nearly 50 per cent. that of similar concrete made with adulterated aluminous cement.

The use of adulterated cement is justified only if the proportion of binding material is increased in such a way as to obtain a sufficient proportion of effective cement. In the case cited it would have been necessary to adopt a proportion of about 400 kg. of adulterated cement per cubic metre; the strength would then have been of the same order as that obtained with a proportion of 200 kg.

of pure cement and the plasticity of the concrete would have been improved. It is quite clear that the cost of binding material per cubic metre of concrete would have been equally increased, thus revealing the illusory economy in the price of adulterated cement.

Comparative tests of contraction and frost resistance on pure cements and cements adulterated with stone dust give the following results.

CONTRACTION.—Generally speaking, adulterated cements show greater contraction than pure cements in mortar (up to 50 per cent. for a content of 16 per cent. of stone dust). On the contrary, the differences are insignificant and sometimes in favour of adulterated cement for the contraction of concrete mixed with 300 kg. of cement and 165 litres of water per cubic metre.

RESISTANCE TO FROST.—The resistance to frost of concretes made with adulterated cement is always notably inferior to that of concretes containing the same proportion of pure cement. The fall in strength after the freezing test is nearly twice as much for concretes made with cement adulterated with 16 per cent. of stone dust as for concretes made with pure cement.

CONCLUSIONS.

(1) The addition of stone dust to cement leads only to illusory economies because the fall of strength of concrete is more rapid than the percentage of adulteration.

(2) The fall of strength of concrete made with adulterated cement is proportionately greater as the nominal percentage of binding material is less.

(3) The relatively favourable strengths shown by standard tests are illusory. They are explained by the particular conditions under which the tests are made.

(4) The true quality of adulterated cement ought to be verified by comparative tests of concrete. The standard tests can introduce an error when the comparison of cements of different natures is concerned.

(5) Adulterated cements have generally a greater contraction than pure cements.

(6) Adulterated cements produce, with equal proportion of binding material, concretes more susceptible to frost action than pure cement.

For these reasons the addition of stone dust to cement should not be permitted.

Air Separation in the Cement and Lime Industries.

THE patented "whizzer" which is now an integral part of Raymond mechanical separators acts as an accelerator in the separating process by throwing the coarse particles out of the air stream and permitting only the fine particles to pass to



Fig. 1.

the finished product chamber. The device (*Fig. 1*) forces the heavy particles down much faster than they would fall by gravity and helps to break up any loose lumps in the feed.

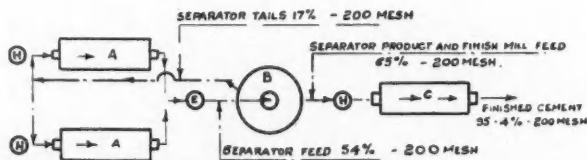
Separation in Cement Plants.

In a test on cement clinker with a 16-ft. separator, an increased output of 155 barrels per hour of material with 90 per cent. passing a 200-mesh sieve was shown with whizzers, as against 113 barrels previously. It is claimed that very close selection of particle size is consistently obtained on fine cement showing less than 0.5 per cent. variation of fineness, and that the device assists in producing

cleaner tailings with a minimum of fines with consequent less regrinding and a higher recovery of fines from the feed to the separator. The following are actual operating records, and show a greater output, more specific surface area, improved quality, and cost reduction resulting from the use of separators in closed circuit grinding.

| | Open circuit | Closed circuit |
|---|---------------------|---------------------|
| Capacity, barrels per hour | 40 | 65 |
| Passing 200-mesh screen | 98.50 per cent. | 99.99 per cent. |
| Passing 325-mesh screen | 94.00 " | 99.99 " |
| Finer than 50 microns | 97.80 " | 99.97 " |
| " " 40 " | 92.70 " | 96.00 " |
| " " 30 " | 87.10 " | 88.50 " |
| " " 20 " | 69.30 " | 72.00 " |
| " " 15 " | 57.50 " | 61.50 " |
| " " 10 " | 42.48 " | 45.80 " |
| Flour | 83.50 " | 90.00 " |
| Specific surface area (sq. cm. per gramme) .. | 2435 | 2654 |
| Tensile strength 1 : 3 mix : | | |
| 1 day | 243 lb. per sq. in. | 330 lb. per sq. in. |
| 3 days | 372 " " | 420 " " |
| 7 " | 465 " " | 476 " " |
| 28 " | 496 " " | 534 " " |
| Total H.P. per barrel | 17.50 | 10.52 |

In a plant equipped with one 16-ft. separator in closed circuit with two Com-Peb mills, two-compartment type, discharging the product to a three-compartment tube mill for regrinding, the operating data are as follows :

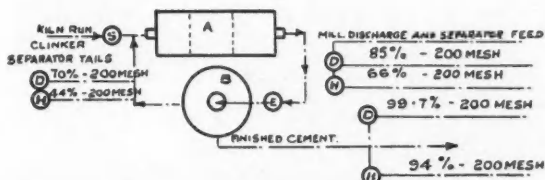


A—Two Com-Peb mills 6 ft. by 24 ft. E—Elevator.
 B—16 ft. separator. H—Com-Peb mill feed hoppers.
 C—Three-compartment tube mill.

| | Open circuit. | Closed circuit. |
|---|---------------|-----------------|
| Total capacity (barrels per hour) | 135 | 178 |
| Finished fineness (per cent. passing 200 mesh) .. | 88 | 95.4 |
| Specific surface area (sq. cm. per gramme) .. | 1500 | 1900 |
| Power per barrel (kW.) | 7.01 | 6.18 |

In the following data relating to one 16-ft. separator in closed circuit with a 7 ft. by 45 ft. three-compartment mill, the former capacity for normal Portland

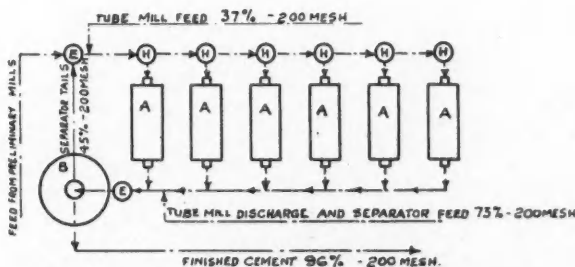
is compared with the present capacity for high-early-strength Portland cement as well as normal Portland cement :



A - Three-compartment mill 7 ft. by 45 ft.
B - 16 ft. separator. D - High-early-strength Portland Cement.
E - Elevator. H - Normal Portland Cement.
S - Mill feed hoppers.

| | Open circuit Normal P.C. | Closed circuit | |
|--|-----------------------------|----------------|--------------------------|
| | | Normal P.C. | High-Early-Strength P.C. |
| Total capacity (barrels per hour) .. | 90 | 130 | 85 |
| Fineness (per cent. passing 200 mesh) .. | 88 | 94 | 99.7 |
| Flour under 30 microns (per cent.) .. | 51 | 54 | — |
| Power per barrel (kW.) .. | 6.28 | 4.99 | 7.58 |

One 16-ft. separator in closed circuit with six 5 ft. by 22 ft. tube mills is giving the following results :



A - Six tube mills 5 ft. by 22 ft. B - 16 ft. separator.
E - Elevator. H - Tube mill feed hoppers.

| | Open circuit. | Closed circuit. |
|---|---------------|-----------------|
| Total capacity (barrels per hour) .. | 120 | 180 |
| Finished fineness (per cent. passing 200 mesh) .. | 88 | 96 |
| Flour under 30 microns (per cent.) .. | 48 | 53 |
| Power per barrel (kW.) .. | 5.33 | 4.55 |

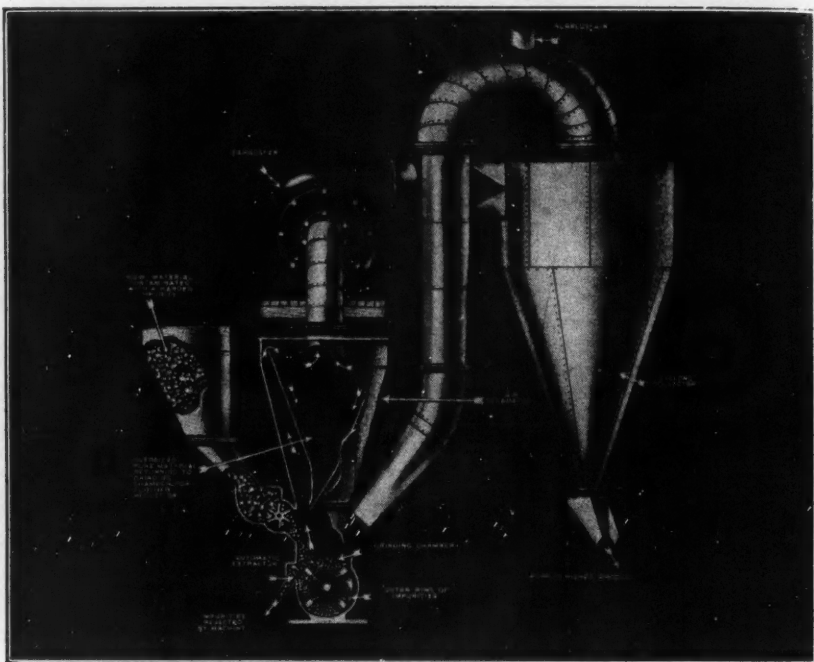


Fig. 2.

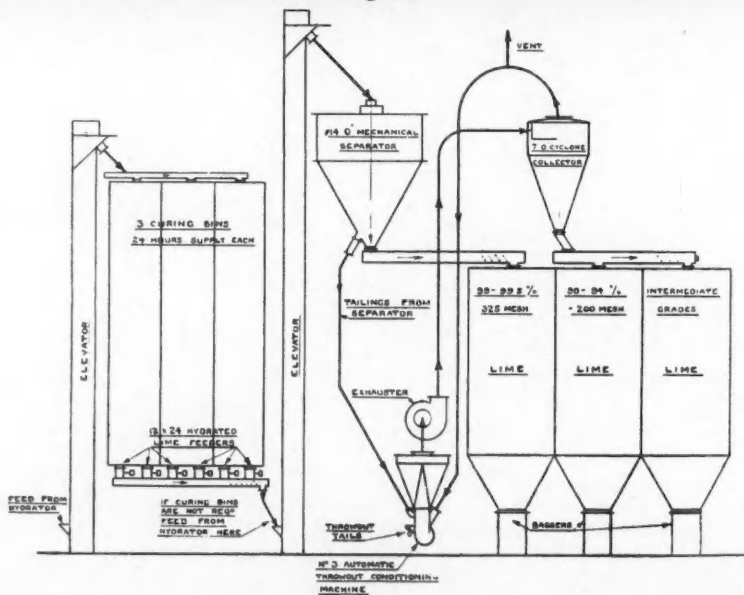


Fig. 3.

When this unit is supplied for the production of hydrated lime it is equipped with a rotor on which are placed renewable manganese steel blades to give at least one year's service. The rotor is operated at a speed sufficient to agitate the lime as it is fed to the machine, so that air can penetrate the revolving

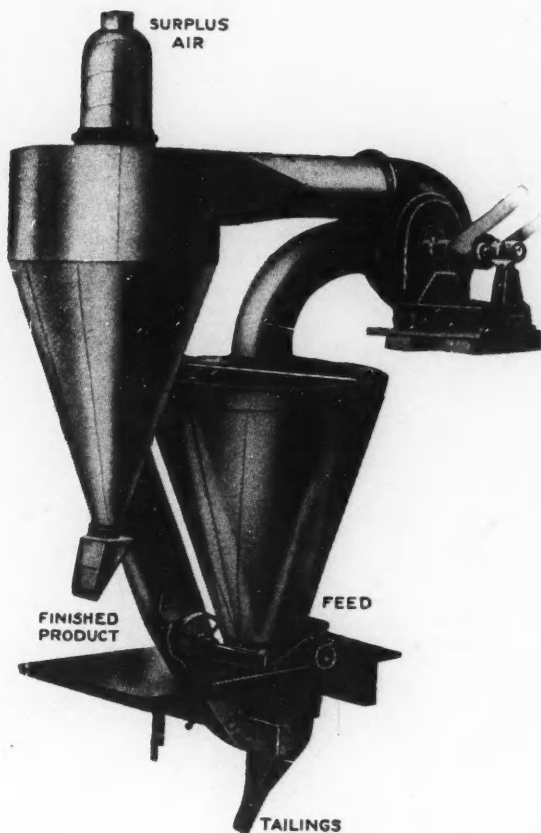


Fig. 4.

material and carry off the fine uniform hydrate, and at the same time segregate the oversize material and hard impurities. The speed of the rotor is arranged to avoid any risk of breaking up impurities. The impurities are ejected from the front of the machine by a throw-out attachment. An illustration of this machine is given in *Fig. 2*.

Mechanical Air-Separation of Hydrated Lime.

A diagram of hydrate air separating and conditioning plant is shown in *Fig. 3*. In this case the mechanical separator is used for taking off the super-fine product or the cream, and the tailings pass on to a Raymond No. 3 conditioning machine which produces material of which 93 per cent. passes a 200-mesh sieve or intermediate grades; the rejects are free from good hydrate fines. Several sizes of mechanical separators are made with capacities from 700 lb. to 7 tons per hour. Mechanical separators can be used for any fineness desired with power requirements from $1\frac{1}{2}$ h.p. for 700 lb. per hour to approximately 22 h.p. for 7 tons per hour. The machine is fitted with whizzers for quickly removing oversize material from the finished product.

Vacuum Separating Plant.

By using more power it is possible to get high capacity, fine separation, and clean tailings. The vacuum air-separating plant is recommended for this combination. The following is an analysis of the product from a plant designed to produce a definite grade:

| Fineness | Amount of fines in rejects |
|---|----------------------------|
| 90 per cent passing 200-mesh B.S.S. . . | Approximately 1 per cent. |
| 95 " " " " " " | " 4 " |
| 99.5 " " " " " " | " 10 " |

The efficiency of air separators is generally proportional to the power taken to overcome the resistances offered in the system to select the particle size necessary to cover specified grades of finished product. *Fig. 4* shows the double-cone classifier for easy control of any requisite fineness with tailings discharge and cyclone fines discharge.

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Design and Operation of Coal Pulverising Plant.

IN view of the increasing use of coal-drying and pulverising plants the following precautions are recommended by the Home Office after discussion with associations representing makers and users of such plants by H.M. Chief Inspector of Factories. The recommendations apply only to plants of the storage or central pulverising type and to unit plants of pulverising capacity greater than 30 cwt. per hour per unit.

(1) All dryers, pulverisers, pulverised-coal bunkers, elevators, cyclones, conveyors, feeders, and pipes carrying pulverised coal should be so constructed and maintained as to prevent, as far as possible, the escape of dust.

(2) The plant should be designed and constructed as far as practicable (a) so that the air velocity at all points in the pipe system where coal is present is sufficient to prevent deposit of dust; (b) so as to avoid internal ledges or pockets where coal dust may remain undisturbed.

(3) The air intake should be protected by wire netting to prevent material, such as oily waste, from being drawn into the system and causing ignition. The position of the netting should be such that burning material arrested thereat cannot ignite coal dust in the plant.

(4)—(a) Explosion-pressure relief doors or panels should be provided on all chambers such as drying chambers, elevator casings, cyclones, bunkers for pulverised fuel, and, where practicable, classifiers. Reliefs are not required on pipes, ducts, or mills constructed to withstand a pressure of 15 lb. per square inch with a normal factor of safety. (b) Relief doors should, where practicable, be so constructed that after being blown open they will close automatically so that the plant will not continue to emit dust. Where a bursting-sheet panel is used, a self-closing door should be fitted outside it unless the relief is vented to the outside air or the chamber is normally under suction. (c) Where practicable, vent pipes should be fitted to connect the reliefs to the outer air; where this is not practicable the reliefs should be so situated or screened that flame issuing from them cannot impinge on any person or ignite any dust outside the plant.

(5) Ample means of escape from all parts of the building should be provided, and, where work is regularly carried on, should include two exits or ladders from each floor or working platform, placed as nearly as practicable at opposite ends. Doors should open outwards wherever practicable; where this is not practicable, sliding doors should be used. No door should open inwards only.

(6) The staff should be instructed in the action to be taken in the event of fire. Provision should be made for extinguishing fires in pulverised coal bunkers.

(7) No person should enter any bunker or other place where there may be dangerous gas, or where he may be engulfed in fuel, unless wearing a life-belt under the control of an attendant outside. The person entering should also wear breathing apparatus unless the bunker (if a closed bunker) has been tested and certified to be clear of dangerous gas and fumes.

(8) All practicable measures should be taken to prevent dust from accumulating on floors, walls, ledges, machinery, and plant.

(9) The use of naked lights, welding plant, or other apparatus likely to cause ignition should not be permitted on any part of the drying or pulverising plant except when it is out of service, and then only after it has been thoroughly cleaned and inspected. Before the plant is put into use after welding or other repairs it should be inspected to ensure that all parts are cold and that no smouldering material is present.

(10) Smoking and the use of naked lights should be prohibited in parts of a building into which open the lids of bunkers containing dried or pulverised coal.

(11) The observance of these recommendations should preclude the existence of inflammable surroundings in the neighbourhood of electrical equipment, but attention is drawn to Regulation 27 of the Electricity Regulations which imposes legal obligations in respect of electrical plant when inflammable surroundings exist.

Recent Patents Relating to Cement.

Cements.

447,722. Southern States Portland Cement Co., Rockmart, Georgia, U.S.A. October 2, 1935.

A cement of the Portland type is made by mixing and grinding two clinkers made by sintering calcareous and argillaceous or siliceous materials, the first clinker containing 30 to 75 per cent. of tri-calcium silicate and substantially no free lime, and the second containing chemically active uncombined silica, calcium alumina di-silicate, and mono-calcium silicate. The two clinkers are preferably mixed in such proportions that the free silica provided by the second clinker is sufficient to combine with all the lime liberated from the tri-calcium silicate of the first clinker on hydration of the cement. The first clinker is fired at a temperature of 1,350 to 1,650 deg. C. and the second at a temperature of 700 to 1,200 deg. C. In an example, a first clinker having a tri-calcium content of 60 per cent. is mixed in equal proportions with a second clinker containing 16 per cent. of chemically active silica.

Admixture for Cement.

458,131. I. G. Farbenindustrie Akt.-Ges., Frankfurt-on-Main, Germany. June 17, 1935.

Water-soluble products of reaction of several molecular proportions of ethylene oxide or a homologue thereof on an organic compound are added to mixes of cement, concrete or mortar, whereby the miscibility of the cement with water is improved. Suitable products are those

of the reactions between ethylene oxide and fatty alcohols, acids, amides, and glycerides, phenols, naphthols and amines. The specification gives further examples of ethylene oxide derivatives, e.g. of casein and stearylamine, and also of other substances, e.g. reaction products of fatty acids and sugars, sugar amines and polyglycerine, sodium abietate, and compounds of alcohols or fatty acid ethanalamides, and polybasic acids, e.g. sulphuric, phosphoric, phosphorous and maleic acids, for addition to cement concretes.

FURNACES WANTED.

SECOND-HAND ROTARY FURNACES WANTED, one 50/80 ft. long by 6/7 ft. diameter, and one 100 ft. or longer by 7 ft. diameter or larger. Write offers to Box 749, Sells Ltd., Brettenham House, Strand, W.C.2.

PATENT.

The Proprietor of British Patent No. 372,044 relating to a "Process for Producing an Improved Lime Suitable for Constructional Purposes," is desirous of securing the full commercial development of the invention in this country either by sale of the Patent outright or by the grant of licences to work thereunder. Interested parties should communicate in the first instance with Eric Potter & Clarkson, 3, Staple Inn, London, W.C.1.